Contact Interactions with Polarized Beams at HERA

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Abstract. The discovery potential of the HERA collider, with and without polarized beams, for electron-quark contact interactions in neutral current scattering is reviewed. The measurement of spin asymmetries in the polarized case could give crucial information on the chiral structure of new interactions.

1. Introduction

The study of contact interactions (CI) is a powerful way to search for departures from the Standard Model and to parametrise new physics phenomena. Phenomenologically at an energy scale much lower than the characteristic scale of the underlying theory, very different new physics contributions can give rise to very similar changes in processes involving only SM particles. The presence of new interactions can then be written in terms of an effective CI Lagrangian in a model-independent way. In the context of HERA the lepton-quark CI of the first generation fermions are the most interesting since they can manifest themselves in $eq \to eq$ scattering. The most general $eeqq$ current-current effective Lagrangian has the form [1]:

$$\mathcal{L}_{eq}^{NC} = \sum_{q=u,d} \sum_{i,j=L,R} \eta_{ij}^q (\bar{e}_i \gamma_\mu e_i)(\bar{q}_j \gamma^\mu q_j) \tag{1}$$

with $\eta_{ij}^q = 4\pi \epsilon_{ij}^q / (\Lambda_{ij}^q)^2$, where Λ_{ij}^q is the effective mass scale of the contact interaction. The sign ϵ_{ij}^q characterises the nature of the interference of each CI term with the Standard Model γ and Z exchange amplitudes. The subscripts LL, RR, LR and RL refer to the chiral structure of the new interaction. In a purely phenomenological approach all η's are unknown parameters, whereas they are predicted in a given theoretical framework. For example, the structure of η_{ij}^q in a generic leptoquark model or in supersymmetry with R-parity violation can be found in Ref [2].

The overwhelming success of the SM suggests that the CI Lagrangian must be $SU(2)_L \times U(1)$ symmetric. The symmetry implies that $\eta_{RL}^u = \eta_{RL}^d$, relates eq and νq NC interactions, and relates the difference $\eta_{LL}^u - \eta_{LL}^d$ to the CC $e\nu ud$ contact term. The lepton-hadron universality of charged-current data indicates that the latter is small.

HERA will be most sensitive to CI terms in measurements at large Q^2 which favours large x where the leading contribution comes from the valence *up*-quark. Therefore, for simplicity, we will assume *u-d* universality, *i.e.* $\eta_{ij}^u = \eta_{ij}^d$. As a result we are left with eight terms in eq. (1) defined by various combinations of chiralities and signs, which we will denote by ij^ϵ, *i.e.* LR^+, LL^- etc.

A global study of the *eq* CI, based on the most relevant existing experimental data, has recently been performed in Ref [3]. Stringent bounds of the order of $\Lambda \sim 10$ TeV for the individual CI terms are found. However, when several terms of different chiralities are involved simultaneously, cancellations occur and the resulting bounds on Λ are considerably weaker and of the order of $3-4$ TeV [3]. Present bounds from HERA as well as from other high-energy experiments are of the same order of magnitude and it can therefore be expected that experiments at HERA will be able to improve the limits with increasing luminosity.

2. Chiral structure of CI: the case for polarized beams

In this note we want to emphasize that the measurement of spin asymmetries, defined in the context of HERA with polarized lepton beams (e^+ and e^-) and/or with polarized lepton and proton beams, could provide very important tools to disentangle the chiral structure of the new interaction. To illustrate the point we will consider an example with double spin asymmetries defined in eq. (2) below. The details of a more complete phenomenological analysis of the experimental signatures of CI from the measurements of cross sections and spin asymmetries in the NC channel at HERA can be found in [4]. The analysis of [4] has been motivated by the renewed interest in the polarization option, considered already at an early stage of the HERA project (see for example [5]), and more recently in [6]; we also refer to the report of the Working Group 6 in these proceedings.

When we discuss polarized beams we split equally the expected total integrated luminosity of 1 fb^{-1} among various configurations of beams and polarizations, *i.e.* for both lepton and proton beams polarized, we assume a luminosity of 125 pb^{-1} for e^+p and e^-p with longitudinally polarized leptons ($\lambda_e = \pm$) and protons ($\lambda_p = \pm$). As a result, the "discovery potential" (as far as the sensitivity to the scale Λ is concerned) is not significantly improved by running with polarized beams as compared to the unpolarized case, see Table 1. There the 95% CL limits for Λ's obtained from the analysis of unpolarized e^+p and e^-p collisions (upper row) are compared to the ones obtained with the help of polarized beams (lower row). In the latter case the following double-spin asymmetries‡ have been used

$$A_{LL}^{PV}(e^-) \; = \; \frac{\sigma_-^{--} - \sigma_-^{++}}{\sigma_-^{--} + \sigma_-^{++}} \qquad \text{and} \qquad A_{LL}^{PV}(e^+) \; = \; \frac{\sigma_+^{--} - \sigma_+^{++}}{\sigma_+^{--} + \sigma_+^{++}} \qquad (2)$$

‡ The asymmetries defined in eq. (2) are sensitive to the violation of parity, and are also interesting from the point of view of spin structure functions [6, 7].

Λ (TeV)	LL^+	RR^+	LR^+	RL^+	LL^-	RR^-	LR^-	RL^-
unpolarized	6.3	6.1	6.2	6.0	5.5	5.3	5.2	5.0
polarized	5.5	6.0	5.3	6.0	5.4	5.8	5.1	5.8

Table 1. Limits on Λ at 95% CL for the unpolarized and polarized cases. In the latter case the double-spin asymmetries of eq. (2) have been used to derive the limits.

which are defined in terms of the polarized differential cross sections $\sigma_l^{\lambda_e,\lambda_p} \equiv \mathrm{d}\sigma_l^{\lambda_e,\lambda_p}/\mathrm{d}Q^2$ with $l = +$ for e^+p and $l = -$ for e^-p. Exploiting other spin asymmetries defined in Ref. [4] (see also [8]) does not improve significantly the limits.

Once new physics effects are observed, polarized beams are very useful since the Q^2 dependence of spin asymmetries contains additional information which is sensitive to the chiral structure. This is exemplified in Fig. 1 where the Q^2 dependence of $A_{LL}^{PV}(e^-)$ and $A_{LL}^{PV}(e^+)$, assuming $\Lambda = 4$ TeV, is drawn for several ij^ϵ CI terms. The observation of a deviation from the SM in e^-p will allow us to distinguish between LL^+/RR^- and LL^-/RR^+, and from e^+p data between LR^+/RL^- and LR^-/RL^+ contact interaction terms. Other spin asymmetries can be exploited to reveal the anatomy of the chiral structure of contact interactions [4].
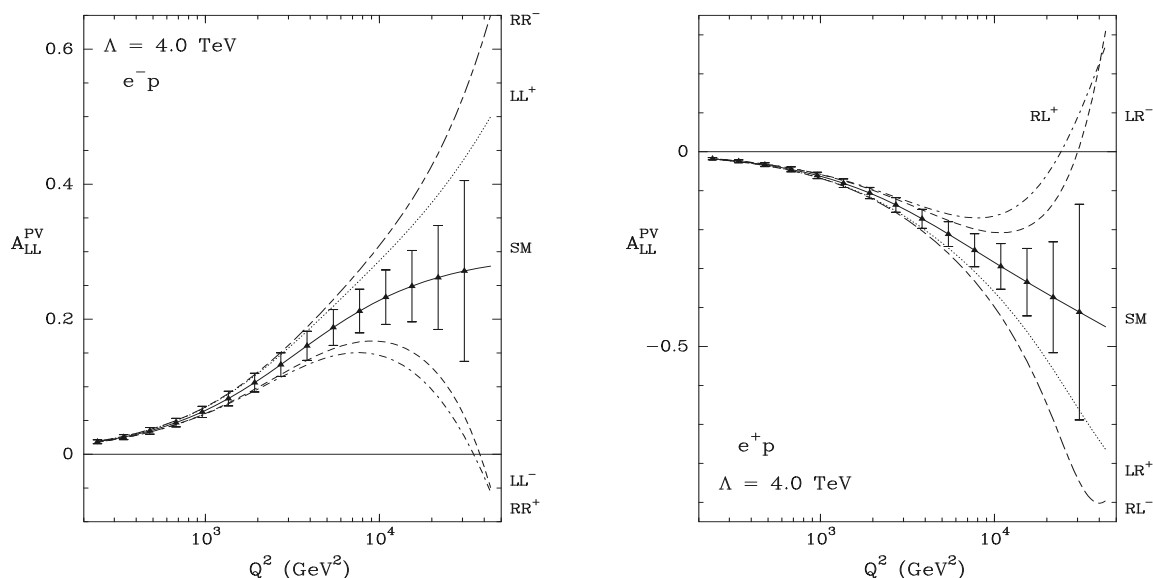

Figure 1. Spin asymmetries $A_{LL}^{PV}(e^-)$ and $A_{LL}^{PV}(e^+)$. Solid lines correspond to the SM prediction; the expected errors are shown assuming a luminosity of 125 pb^{-1} for each configuration of beam polarizations. Non-solid lines correspond to CI scenarios with $\Lambda = 4$ TeV and helicities as indicated.

3. Conclusions

The main conclusions are the following:

1) The HERA collider with an integrated luminosity of $L_{tot} = 1$ fb^{-1} will give strong bounds on the energy scale of a possible new CI. For constructive interferences, the limit on Λ is of the order of $6\,TeV$, and for destructive interferences we get $\Lambda \sim 5\,TeV$. The availability of polarized lepton and proton beams will not increase significantly these bounds, except for destructive interferences. With only leptons polarized, the sensitivity is strongly reduced.

2) The studies of spin (and charge) asymmetries can give unique information on the chiral structure of the new interaction. The availability of electron and positron beams is mandatory in order to cover all the possible chiralities.

3) Since in the proton the valence u-quark distribution is dominant, the measurements essentially constrain the presence of a new interaction in the eu sector. To constrain a new interaction in ed sector, protons could be replaced by neutrons, for example by using electron-He^3 collisions, an option which is also under consideration at HERA [6].

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5. References

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